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(54) Abstract Title
**A rake receiver wherein each finger has a DLL and at least one has early and late correlators connected via a controllable bandwidth filter to a subtractor**

(57) A rake receiver (40) has a plurality of fingers, each finger having associated therewith a delay locked loop (DLL) arranged to control its respective finger to track a component of a received signal. The DLL of at least one finger comprises early and late correlators (22) connected to respective inputs of a subtractor (31) via respective filter elements (41, 42). The filter elements (41, 42) each include a respective controllable bandwidth filter. Preferably the rake receiver comprises an estimator (part of controller 48) in order to estimate channel dynamics, these estimated dynamics being used to control the controllable bandwidth filters. Further preferable features include the controller being used to estimate autocorrelation of the signal provided by one of the correlators and use of FIR filters or averagers as filters (43, 46). The rake receiver finds particular application in a universal mobile telephone system (UMTS) wherein it is used to receiver a common pilot channel (CPICH), measurement of which allows inferences about how signals propagate over the channel.

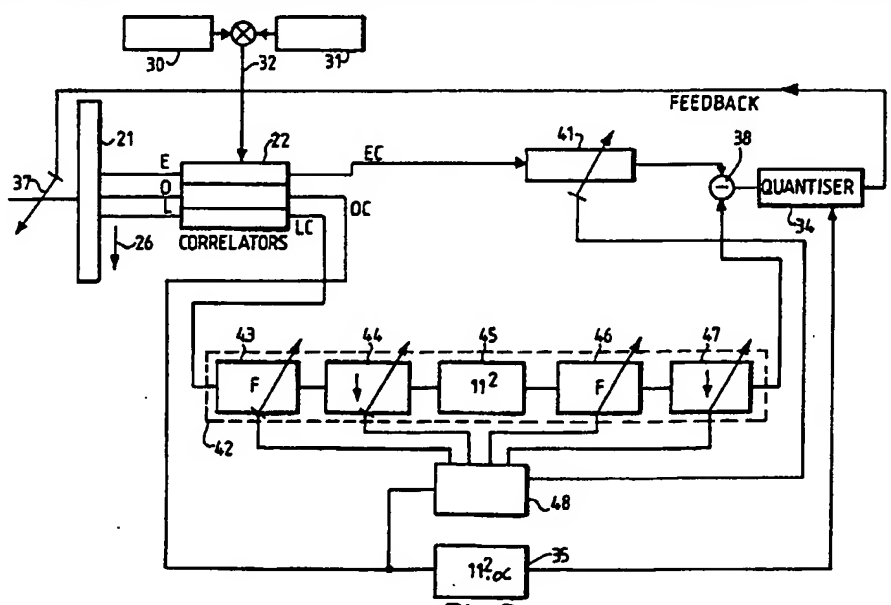


Fig.3.

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

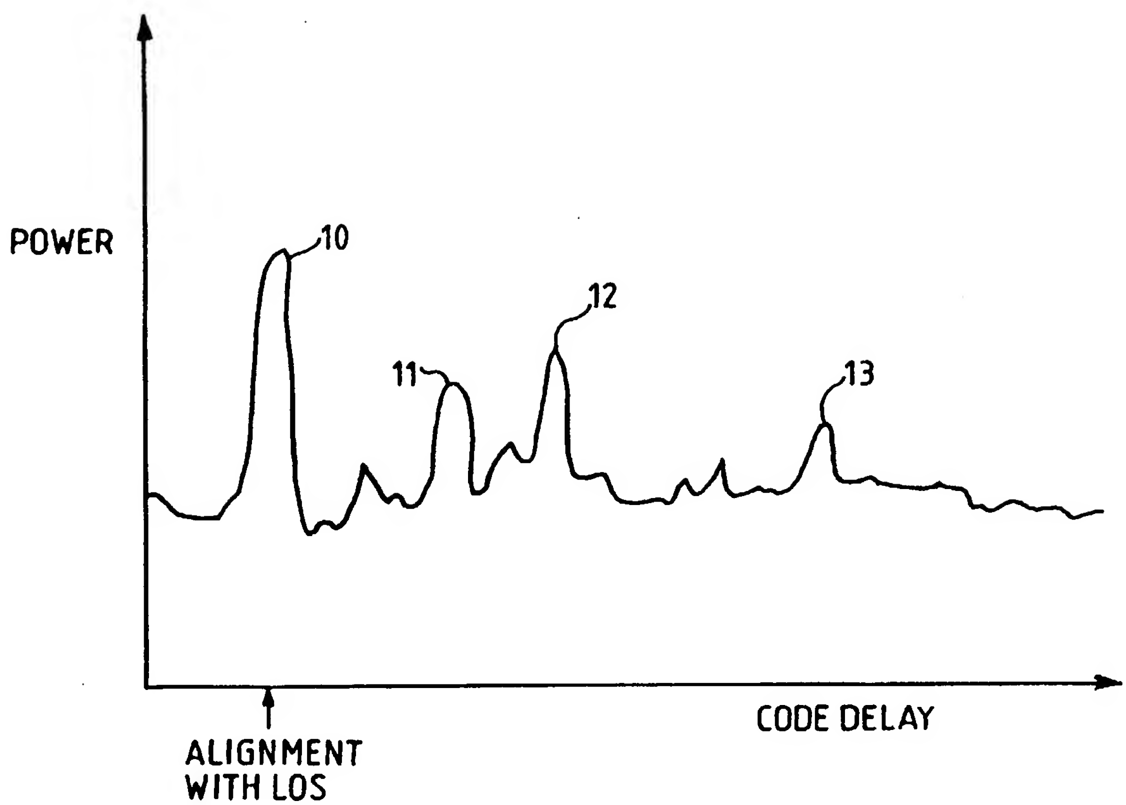


Fig.1.

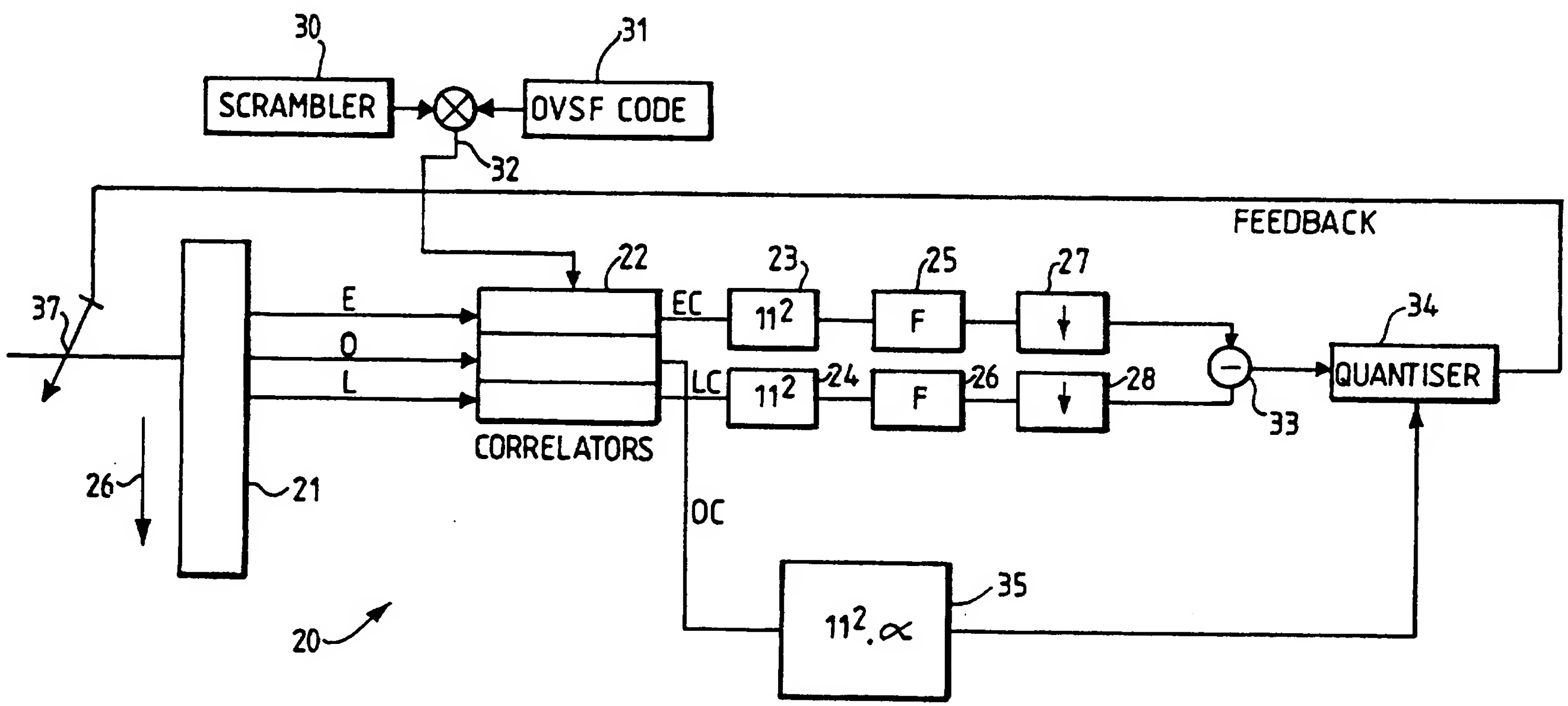
30
SCRAMBLER
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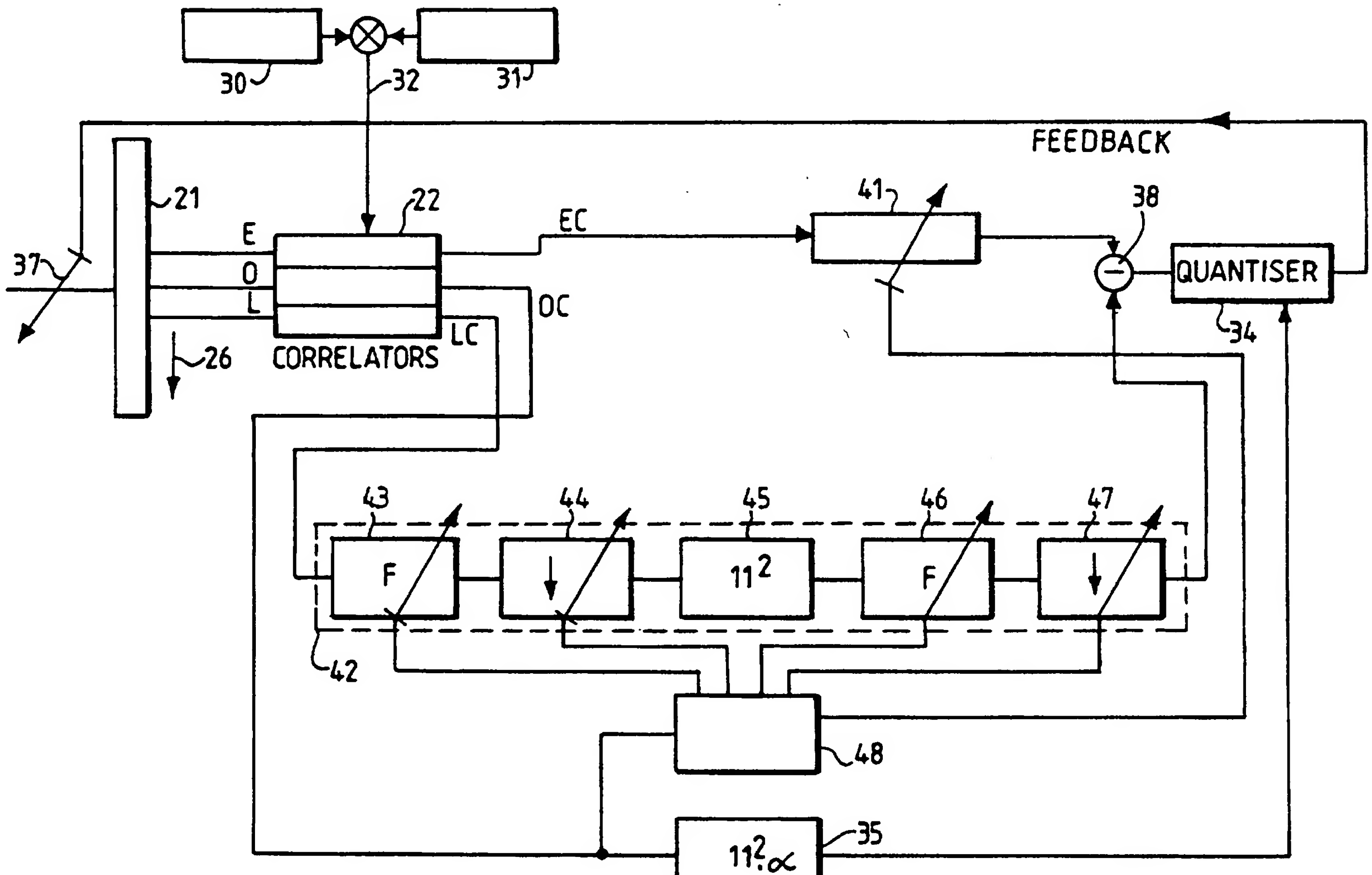
Fig.2.



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CORRELATORS
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QUANTISER
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F
$11^2$
F
42
48
35
$11^2 \cdot \alpha$


Fig.3.

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## A Rake Receiver

This invention relates to a rake receiver.

It is common in wideband code division multiple access (W-CDMA) radio receivers to use a rake receiver to process a received signal. A rake receiver comprises a number of correlators, typically four correlators, which are arranged in parallel with their outputs being applied to an adder. The output of the adder is the output signal for the rake receiver. Each correlator can be called a 'finger', and each finger is independently controllable. Since it is necessary to generate a pseudo-random noise (PN) code at the same frequency and phase as the code which is modulated onto the received signal to achieve correlation with a line-of-sight (LOS) signal, it is possible to isolate delayed multipath signals by mixing a delayed version of the code with the received signal. The code delay must be equal to the time delay between the LOS signal and the multipath signal for correlation to occur. In practice, due to receiver limitations and the effects of noise, a characteristic such as that shown in Figure 1 may be obtained.

In Figure 1, amplitude is plotted against code delay for a signal which is received over a short period in time. The LOS signal 10 is clearly visible as the strongest, since it has the largest amplitude. Multipath signals 11, 12, 13 are also visible at various places along the code delay axis (or code space), each having an amplitude independent to the others. Although not visible from this figure, each component of the signal has its own carrier phase. Each finger of the rake receiver is controlled to follow a component or ray 10-13 of the received signal. Usually, one finger follows the LOS ray 10, and the other fingers each follow a multipath ray 11-13. Often, however, the LOS ray 10 is not sufficiently strong, in which case each finger may follow a different multipath ray. A finger includes a mixer and a delay element which operate in such a way that a correlated signal is provided. The carrier phase of the correlated signal is brought to an arbitrary value, which is the same value for each finger, and the amplitude of each signal is adjusted according to a conventional algorithm. The signals from all the fingers are then added by the adder, thereby obtaining efficient signal reception from

the received signal. The rake receiver, in effect, 'rakes' the code space for relevant rays, brings them into line with each other, in time and carrier phase, and then sums them. A rake receiver provides a significant increase in signal-to-noise ratio (SNR) compared to a receiver which operates only on the LOS ray or on a multipath ray.

As the receiver moves relative to a transmitter, such as a cellular base station, the characteristic shown in Figure 1 changes in a number of ways. Most significantly, destructive superposition causes the power of the rays to rise and fall by very significant amounts, with the rate and frequency of the power changes being dependent particularly on the dynamics of the propagation channel. The multipath rays 11-13 also move along the code space, one way or the other, as the difference in the lengths of the signal paths change relative to the LOS path. The carrier phase of the signals also changes over time, albeit more slowly.

To detect the rays of the received signal, and to track them with time, it is known to use a delay locked loop (DLL) with each finger. Since the rays 10-13 tend to have a usable width of about one chip (a chip being the shortest possible distance between transitions of the modulating PN code), each finger may sample the code space at three code positions regularly spaced over a distance of one-half of a chip. Here, the sample at the earliest phase of the code is called the early sample, the on-time and the late samples being of increasingly greater code phase. The degree of misalignment of a given finger with the ray being tracked and the direction of misalignment are detected by comparing the power of signals from the early sample with the power of those from the late sample. The difference in power and the sign of the difference are provided as a feedback signal to control the movement of the finger along the code space. This is known as a non-coherent DLL, since the carrier phases of the signals are not taken into account by the DLL.

It is currently proposed for the universal mobile telephone system (UMTS) for each base station to transmit a continuous pilot signal (a datastream of all logic "ones") on a dedicated pilot channel, called a CPICH channel, having its own channel specific OVSF code which is modulated onto the signal at the base station. This allows

hardware in a radiotelephone to track continuously signals received over the CPICH channel, to make measurements thereof and to infer from these measurements the nature of the channel and therefore how signals are propagated over the channel. Since data channels occupy the same bandwidth as the pilot channel, characteristics of the data channels can be determined without measurement of signals received over the data channels. It is proposed for the transmitter power of data channels to be controlled by the receiver (base station or radiotelephone) which receives the data channels. However, CPICH channels will be received by all radiotelephones and will, therefore, be transmitted at a constant power level.

Referring to Figure 2, a conventional rake receiver 20 comprises generally a signal delay element 21, and a bank of correlators 22. The bank of correlators 22 forms part of a finger of the receiver. The signal delay element 21 is schematic. It can be thought of as a tapped delay line from which outputs show a signal received at successive delays equal to one-quarter of a chip period of the channel specific OVSF code. The distance in code space between a pair of adjacent outputs is the reciprocal of the oversampling factor (OSF) of the receiver. The further along the delay element 21, in the direction of the arrow 26, the output is, the greater the amount that the received signal is delayed. The finger may process the LOS signal 10 or a multipath signal 11-13. The receiver includes other, identical fingers (not shown) which track other ones of rays received over the CPICH channel.

The finger receives signals from three successive outputs of the delay element 21, namely an early signal E, an on-time signal O and a late signal L. Since the outputs of the delay element 21 are spaced one-half of a chip apart, the E and the L signals are separated by one chip. A scrambling code generator 30 provides a scrambling code which is unique to the transmitter (not shown), which is, for example, a cellular telephone base station, and an OVSF code generator 31 provides the OVSF code which is unique to the CPICH channel. The receiver 20 may be, for example, part of a cellular telephone radio receiver. The scrambling code generator 30 and the OVSF code generator 31 are controlled in phase and in frequency in a conventional manner. The bank of correlators 22 mix the composite signals provided on a mixer output 32 with

each of the E, O, and L signals in parallel, to generate correlated signals EC, OC and LC respectively, each having a real and an imaginary part.

The signals EC, OC and LC are complex samples of the signals found around the crests of the rays forming the received signal, such as the ray 11 of Figure 1. The EC and LC signals are provided to respective modulus square operator devices 23, 24, which in effect calculate the power of the EC and LC signals and provide the results to respective downsamplers 27, 28 via respective non-coherent filters 25, 26. Neither the downsamplers 27, 28 nor the filters 25, 26 are controllable, rather the downsampling rate of the downsamplers 27, 28 and the characteristics of the filters 25, 26 are predetermined in the design stage as a compromise between optimum performance and receiver complexity. In the modulus square operator devices 23, 24, the square of the modulus is taken, rather than the modulus itself, since a modulus operation involves a square root calculation, which is expensive in terms of hardware. The non-coherent filters 25, 26 are low-pass filters which 'smooth' the signals provided at their respective inputs. In practise, the low-pass filters 25, 26 are usually simple averagers.

Outputs of the downsamplers 27,28 are connected to respective inputs of a subtractor 33, which provides a signal representative of the difference between the signals provided by the downsamplers 27, 28 and of the sign of the difference to a signal input of a quantiser 34. The OC signal from the on-time one of the bank of correlators 22 is received by a calculator device 35, which calculates the modulus square of the OC signal and multiplies it by a constant, *a*, which is typically 0.6. The result is provided to a threshold input of the quantiser 34 as a threshold signal.

The quantiser 34 is able to provide one of three output signals, being "plus one", "zero," or "minus one". The output "plus one" is given if the signal received at its signal is greater than the threshold signal, "minus one" if the signal received at its signal input is less than the negative of the threshold signal, and "zero" is given otherwise. The output signal of the quantiser 34 is fed back to a control input 37 of the delay line 21, to effect movement there along in order to align the finger more closely with the received signal. The value of *a* selected determines the degree of

misalignment that must be present between the finger and the ray before the quantiser 34 provides a feedback signal which effects movement along the delay line.

After signal acquisition, the position of each finger is updated by its respective DLL. Further resources are allocated to searching the code space for new signals, to which finger allocation may be desirable.

Each finger also has an amplitude detector (not shown) and a carrier phase detector (not shown) associated with it. Signals from these detectors are used to modify the signals provided by the fingers before they are provided to the adder.

It is an aim of the invention to provide an improved rake receiver.

In accordance with this invention, there is provided a rake receiver having a plurality of fingers, each finger having associated therewith a delay-locked-loop arranged to control its respective finger to track a component of a received signal, the delay-locked-loop of at least one finger comprising early and late correlators connected to respective inputs of a subtractor via respective filter elements, characterised in that the filter elements each include a respective controllable bandwidth filter.

Advantageously, the rake receiver further comprises an estimator arranged to estimate the dynamics of the channel over which the rake receiver receives the received signal, and a controller arranged to control the controllable bandwidth filters on the basis of the estimated dynamics. The estimator may be arranged to estimate the autocorrelation of a signal provided by a correlator, preferably an on-time correlator, forming part of the finger. The estimator is preferably arranged to calculate the ratio of the estimated autocorrelation sequence at a first moment in time to the estimated autocorrelation at a subsequent moment in time, thereby to estimate the dynamics of the channel.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings, of which:

Figure 1 shows a correlation plot of a typical received signal;

Figure 2 schematically show a parts of a typical rake receiver; and

Figure 3 shows schematically part of a rake receiver according to the invention.

Figure 3 shows part of a rake receiver 40 according to this invention, with reference numerals retained from Figure 2 for like elements. The receiver 40 includes a filter element 41 interposed between the subtractor 31 and the early one of the bank of correlators 22. An identical filter element 42 is interposed between the subtractor 31 and the late one of the bank of correlators 22. The filter element 42 is broken down into its constituent parts, namely, in sequence, a variable bandwidth coherent filter 43, a first controllable downsampler 44, a modulus square operator device 45, a variable bandwidth non-coherent filter 46 and a second controllable downsampler 47.

The downsample rates of the downsamplers 44, 47 and the bandwidths of the filters 43, 46 are controlled by a controller 48, which is connected to the output of the on-time one of the bank of correlators 22. The controller 48 is connected to the corresponding devices in the filter element 41 in an identical manner.

The controller 48 includes an estimator which deduces a measure of the dynamics of the propagation channel between the transmitter (not shown) and the receiver 40, as regards the ray that the finger is tracking. This is performed through the implementation of a joint adaptation cost function or algorithm. The controller 48 estimates the autocorrelation of the complex signal provided by the on-time one of the bank of correlators 22. The length of the autocorrelation is predetermined.

The autocorrelation is computed, within an ergodic assumption on a boxcar sliding of N samples of the sample correlation (boxcar denotes a flat response);

To avoid taking bias caused by noise into account, and to avoid expensive square root operations, the autocorrelation is normalised to the first sample of a given sequence. The ratio of the autocorrelation result at a given time to the autocorrelation result at a time shortly thereafter is a measure of the mobility of the receiver.

In a first embodiment, the filters 43 and 46 are merely averagers. When low channel dynamics are detected by the controller 48, emphasis is given to the coherent filter 43 over the non-coherent filter 46. This is achieved by controlling the coherent filter 43 to average its input signal over, for example 16 or 32 samples, and by controlling the first downsampler 44 to have a downsampling rate of eight times. The non-coherent filter 46 is controlled to filter its input signal over only, for example, four or two samples, and the second downsampler 47 is controlled to have a downsampling rate of two or even only one. Giving emphasis to the coherent filtering in this way causes the receiver 40 to be less susceptible to interference, such as interference which can result from cross-correlation code leakage, giving rise to an increase in signal-to-noise ratio (SNR). The number of samples over which a filter 43, 46 averages its input signal can be termed the length of the filters.

When high channel dynamics are detected by the controller 48, emphasis is instead given to the non-coherent filter 46. This is achieved by controlling the coherent filter 43 to average over four or two samples, and controlling the non-coherent filter to average over 16 or 32 samples. The downsampling rates of the downsamplers 44 and 47 are reversed compared to the low channel dynamics situation.

In a second embodiment, the filters 43, 46 each are a finite impulse response (FIR) low-pass filter having a fixed length but having a controllable cut-off frequency and, therefore, bandwidth.

Control of the filters 43, 46 and the downsamplers 44, 47 is performed dynamically with updates being effected at intervals sufficient to perform well in fast fading channel environments.

This invention provides improved immunity to ray tracking errors, both with LOS signals and with multipath signals. Moreover, it is possible to implement the invention with hardware having a relatively low computational complexity.

The rake receiver of the invention does not need for a priori tuning since the estimation of the pilot autocorrelation sequence allows indirect filter tuning.

Although the invention has been described operating in respect of a continuous pilot channel, it will be appreciated that the invention could be applied also to time multiplexed pilot channels. In this case, additional considerations may need to be made, for example limiting the length of the autocorrelation in line with the duration of any power control period.

Instead of the tapped delay line implementation, it is possible to perform the invention using a "small" memory scheme in which finger alignment occurs by varying the phase of the scrambling sequence (including the OVSF code and the unique transmitter code), and mixing this with the received signal. In this implementation, each finger uses a different code phase, and there is no phase difference between the received signal in each of the different fingers.

## Claims

1. A rake receiver having a plurality of fingers, each finger having associated therewith a delay-locked-loop arranged to control its respective finger to track a component of a received signal, the delay-locked-loop of at least one finger comprising early and late correlators connected to respective inputs of a subtractor via respective filter elements, characterised in that the filter elements each include a respective controllable bandwidth filter.

2. A receiver according to claim 1, in which the filter elements each include, in sequence, a controllable bandwidth coherent filter, a power estimator device, and a controllable bandwidth non-coherent filter.

3. A receiver according to claim 2, in which the power estimator devices are modulus square operator devices.

4. A receiver according to any preceding claim, in which at least one of the filters is succeeded by a downsampler having a controllable downsampling rate.

5. A rake receiver according to any preceding claim, further comprising an estimator arranged to estimate the dynamics of the channel over which the rake receiver receives the received signal, and a controller arranged to control the controllable bandwidth filters on the basis of the estimated dynamics.

6. A rake receiver according to claim 5, in which the estimator is arranged to estimate the autocorrelation of a signal provided by a correlator forming part of the at least one finger.

7. A rake receiver according to claim 6, in which the correlator is an on-time correlator.

8. A rake receiver according to claim 5 or claim 6, in which the estimator is arranged to calculate the ratio of the estimated autocorrelation at a first moment in time to the estimated autocorrelation at a subsequent moment in time, thereby to estimate the dynamics of the channel.

9. A rake receiver according to any preceding claim, in which some or all of the filter elements are averagers of controllable lengths.

10. A rake receiver according to any preceding claim, in which some or all of the filter elements are finite impulse response filters having controllable cut-off frequencies.

11. A rake receiver substantially as shown in and/or as described with reference to figure 3 of the accompanying drawings.

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11.

**Application No:** GB 0101860.5
**Claims searched:** 1-11

**Examiner:** Paul Jefferies
**Date of search:** 25 July 2001

# Patents Act 1977
# Search Report under Section 17

**Databases searched:**

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.S): H3Q(QDRX); H4P (PAN, PDCSL)

Int Cl (Ed.7): H04B 1/707; H04L 7/04

Other: ONLINE: WPI, EPODOC, JAPIO

**Documents considered to be relevant:**

| Category | Identity of document and relevant passage | | Relevant to claims |
|---|---|---|---|
| A | GB 2349555 A | (ROKE MANOR RESEARCH) See particularly Abstract and figure 2. | |
| A | EP 1041727 A2 | (INTERDIGITAL) See particularly column 18, paragraph [0081]. | |

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